Physics 280: Session 14

Plan for This Session

Questions

Midterm Exam, Thursday March 17\textsuperscript{th}

\begin{itemize}
\item midterm will cover modules 1 to 5 + news
\item old tests available for practice on course web-page
\item 50\% of problems will be from old exam
\item additional review session, Sunday, March 13\textsuperscript{th}, 3-5pm
\end{itemize}

News

Module 5: Nuclear Weapon Delivery Systems
U.N. Toughens Sanctions on North Korea in Response to Its Nuclear Program

By SOMINI SENGUPTA and CHOE SANG-HUN  MARCH 2, 2016

UNITED NATIONS — Exasperated with North Korea’s defiant testing of nuclear bombs and ballistic missiles, the United Nations Security Council voted unanimously on Wednesday to severely toughen its penalties against the isolated country.

The development also reflected closer cooperation between the United States and China on a longstanding dispute. The 15-member Council approved a resolution, negotiated for weeks by American and Chinese officials, that called for inspecting all cargo going in and out of the country, banning all weapons trade and expanding the list of individuals facing sanctions.

Diplomats said the resolution contained the most stringent measures yet to undermine the North’s ability to raise money and secure technology and other resources for its nuclear weapons program. Much depends, however, on whether China — North Korea’s leading trade partner and diplomatic shield — will enforce it. Samantha Power, the American ambassador to the United Nations, called the resolution “comprehensive, robust and unyielding,” and said enforcement must be as well.
On Thursday morning, hours after the resolution passed, North Korea launched what appeared to be several short-range missiles off its east coast, the South Korean Defense Ministry reported.

The Security Council measure is a narrow, diplomatic convergence between the United States and China. Beijing has repeatedly said it opposes Pyongyang’s development of a nuclear weapons arsenal, and publicly rebuked the North on Wednesday for carrying out nuclear and rocket tests this year in “defiance” of international prohibitions.

China signaled that it saw the resolution as spurring peace talks soon, a goal that was welcomed by nonproliferation advocates. Darryl Kimball of the Arms Control Association said the resolution could be useful as leverage to persuade Pyongyang to return to the bargaining table. But he also criticized the Obama administration’s policy of “insisting on denuclearization as a precondition for talks to halt and reverse North Korea’s advancing nuclear and missile capabilities.”

“In the next several weeks, it will be important for Washington and Beijing to communicate to Pyongyang that they are willing to formally resume negotiations,” Mr. Kimball argued.
U.S. test-fires ICBMs to stress its power to Russia, North Korea

By DAVID ALEXANDER

VANDENBERG AIR FORCE BASE, CALIF. | Fri Feb 26, 2016 9:36am EST

The U.S. military test-fired its second intercontinental ballistic missile in a week on Thursday night, seeking to demonstrate its nuclear arms capacity at a time of rising strategic tensions with Russia and North Korea.

The unarmed Minuteman III missile roared out of a silo at Vandenberg Air Force Base in California late at night, raced across the sky at speeds of up to 15,000 mph (24,000 kph) and landed a half hour later in a target area 4,200 miles (6,500 km) away near Kwajalein Atoll in the Marshall Islands of the South Pacific.

Deputy Defense Secretary Robert Work, who witnessed the launch, said the U.S. tests, conducted at least 15 times since January 2011, send a message to strategic rivals like Russia, China and North Korea that Washington has an effective nuclear arsenal.

"That's exactly why we do this," Work told reporters before the launch.

"We and the Russians and the Chinese routinely do test shots to prove that the operational missiles that we have are reliable. And that is a signal ... that we are prepared to use nuclear weapons in defense of our country if necessary."

Demonstrating the reliability of the nuclear force has taken on additional importance recently because the U.S. arsenal is near the end of its useful life and a spate of scandals in the nuclear force two years ago raised readiness questions.
Module 5: Delivery Systems

Part 1: Overview of nuclear weapon delivery methods

Part 2: Aircraft

Part 3: Cruise missiles

Part 4: Ballistic missiles

Part 5: Technical and operational aspects

Part 6: Nuclear command and control
Part 1: Overview
Basic Propulsion Mechanisms

- **None**
  (examples: mines, depth charges)

- **Explosives**
  (example: artillery shell)

- **Propellers**
  (example: torpedo, speeds ~ 50 mph)

- **Jet engines**
  (example: bomber, speeds ~ 600 mph)

- **Rocket motor**
  (example: missile, speeds ~ 18,000 mph)

- **Unconventional**
  (examples: barge, boat, Ryder truck, backpack, shipping container)
Examples of Weapon Delivery Methods

Air-breathing vehicles —
• Aircrafts (manned)
• Cruise missiles (unmanned aircraft)

Rocket-propelled vehicles —
• Land-based ballistic missiles
• Submarine-based ballistic missiles
• [Surface ship-based ballistic missiles]*
• [Space-based ballistic missiles]*
• Short range rockets (no guidance)

Other —
• Artillery/howitzers
• Land mines
• Torpedoes

* Never deployed by US or USSR/Russia for nuclear weapons
Important Attributes of Delivery Systems

• Range
• Speed
• Accuracy
• Recallability
• Reliability
• Payload/throw-weight
• Ability to penetrate defenses
• Survivability (at deployment base)
• Capital and operational costs
• Safety
Air-Breathing Vehicles

Aircraft (manned) —

• Long-range (“heavy”) bombers (examples: Bear, Blackjack, B52, B-1, B-2)
• Intermediate-range bombers (examples: B-29, FB-111, …)
• Tactical aircraft (examples: F-16, F-18, F-22, …)

Cruise missiles (unmanned) —

• Air-launched cruise missiles (ALCMs)
• Sea-launched cruise missiles (SLCMs)
• Ground-launched cruise missiles (GLCMs)
Rocket-Powered Vehicles

Land-based ballistic missiles —
• Intercontinental-range ballistic missiles (ICBMs)
• Shorter-range ballistic missiles

Sea-based ballistic Missiles —
• Submarine-launched ballistic missiles (SLBMs)
• Surface-ship-launched ballistic missiles
Historical Examples of Other Nuclear Weapon Delivery Methods

Nuclear artillery shells:
- 16” naval guns
- 280 mm cannons (howitzer)

"Atomic Annie" 1953: 15-kt projectile to range of 17 miles

Davy Crocket Nuclear Bazooka
- 76 lb., 10–250 t yield, 1.2–2.5 mile range
- Deployed 1961–1971; 2,100 produced

Atomic Demolition Munitions (ADMs)

Carried by back pack, 0.01 kt yield?

Nuclear-armed torpedoes
Initially US nuclear weapons delivery systems were developed without an overall coherent plan, in the —

- Truman administration
- Eisenhower administration

McNamara (Kennedy’s Secretary of Defense) changed this —

- Survivable basing
- Secure command and control
- Determine how much is enough by calculation!

  Concluded 400 ‘effective’ megatons (EMT) would be “enough”

- The need to organize the roles for the USAF and the USN defined the “Triad” paradigm
- Established the SIOP (Single Integrated Operational Plan) for targeting
The U.S. Cold-War Strategic “Triad” – 2

Strategic nuclear delivery vehicles (SNDVs) —

The definition of “strategic” nuclear weapons was important for arms control but was controversial during the Cold War: the Soviet Union wanted to count weapons on its periphery whereas the U.S. did not want to count these:

- Systems with intercontinental range (U.S. def.)
- Systems able to strike directly the homeland of the adversary (Soviet def.)

Systems in the Triad —

- Intercontinental-range bombers
- Intercontinental-range ballistic missiles (ICBMs)
- Submarine-launched ballistic missiles (SLBMs)
Module 5: Nuclear Delivery Systems

Part 2: Aircraft
Examples of Intercontinental Bombers – 1

- **Tu-95**
  - **BEAR**
  - UNREFUELED COMBAT RADIUS (KM): 8,300
  - MAX SPEED (MACH): 0.8

- **Tu-22**
  - **BACKFIRE**
  - UNREFUELED COMBAT RADIUS (KM): 4,000
  - MAX SPEED (MACH): 2.0

- **Tu-160**
  - **BLACKJACK**
  - UNREFUELED COMBAT RADIUS (KM): 7,300
  - MAX SPEED (MACH): 2.0

- **Numbers**
  - Tu-95: 65
  - Tu-22: 160
  - Tu-160: 16

FKL, Dep. of Physics © 2016
Examples of Intercontinental Bombers – 2

### US Bomber Aircraft

<table>
<thead>
<tr>
<th></th>
<th>Meters</th>
<th>B-1</th>
<th>B-52</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unrefueled Combat Radius (km)</td>
<td>1,480</td>
<td>7,500</td>
<td>8,000</td>
</tr>
<tr>
<td>Max Speed (Mach)</td>
<td>2.5</td>
<td>1.25</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>FB-111</td>
<td>B-1B</td>
<td>B-52G/H</td>
</tr>
<tr>
<td>Length</td>
<td>60</td>
<td>45</td>
<td>75</td>
</tr>
<tr>
<td>Width</td>
<td>30</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>0</td>
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</tr>
</tbody>
</table>

B-1: 65
B-52: 75
U.S. B-2 Stealth Bomber

Speed: Mach 0.85
Altitude: 50,000 feet
Range: 7,000 miles
Refuel: 11,500 miles

Possible payloads:
• 16 B83 gravity bombs
• 20 B61 bombs
• 80 500 lb bombs

# of B-2s 20
Currently Deployed U.S. and Russian Bombers

Current US bombers —
- B-52 carrying bombs, or cruise missiles
- B1 each can carry 16 B83 bombs
- B-2 each can carry 16 B83 bombs

Russian bombers* —
- Bear carrying bombs
- Blackjacks carrying bombs

*few are currently operational
Intercontinental Bomber Issues

Evolution of bomber missions —

• High-altitude bombing
• Low-altitude penetration and bombing
• As a stand-off launch platform for Air-launched cruise missiles (ALCMs)

Operational considerations —

• Launch, release to targets, and arming of weapons requires permission from the National Command Authority (NCA) (in the United States, the President or his designated successor)
• Can be recalled until weapons (e.g., bombs, cruise missiles, or air-to-surface ballistic missiles) are dropped or fired from the bomber
• The United States has substantial in-flight refueling capability; other countries have none
iClicker Question

Which one of the following is not one of Richardson’s “Three Goals of Terrorists”?

(A) Revenge
(B) Reaction
(C) Resources
(D) Renown
iClicker Question
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Which one of the following delivery vehicles was not considered a leg of the Cold War nuclear “Triad”?

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(D) Land-based intercontinental bombers
Module 5: Nuclear Delivery Systems

Part 3: Cruise Missiles
Cruise missiles (CMs) are pilotless vehicles powered by jet engines:

- Fly within the atmosphere
- Speeds are subsonic

Although cruise missiles were conceived 60 years ago, CMs did not become important until the late 1970s, when technological advances made them militarily useful. These advances were:

- Smaller and lighter nuclear warheads
- Efficient turbofan engines
- Highly capable miniaturized computers
- GPS, TERCOM (Terrain Contour Matching), and terminal guidance
- “Stealth” airframe technology
Introduction to Cruise Missiles – 2
(Important)

Key properties —

• Small
• Easily stored and launched
• Highly penetrating
• Versatile
• Highly accurate
• Very cheap (about ~ $1 million per copy)
Long-Range Cruise Missiles – 1

Long-Range Cruise Missiles

Russia (USSR)

- SS-NX-21*
- AS-15
- SSC-X-4*

US

- SS-NX-24*
- GLCM**
- ALCM
- TOMAHAWK
  - GLCM
  - SLCM

Range: 1000 – 2000 miles
Pay loads: 500 – 1200 lbs
Long-Range Cruise Missiles – 2

Conventionally-Armed Tomahawk Cruise Missile

- velocity: 550 mph
- pay load: 1000 lbs
- range: 1550 miles
Chinese Silkworm Anti-Ship Cruise Missile

Chinese CSS-C-2 SILKWORM / HY-1 / SY-1 Anti-Ship Cruise Missile

Velocity: 680 mph
payload: 660 lbs
range: 180 miles
Launching Cruise Missiles – 1
Launching Cruise Missiles – 2
Cruise-Missile Guidance – 1

TERCOM: Terrain Contour Matching
DSMAC: Digital Scene Matching Area Correlation
Cruise-Missile Guidance – 3

Tomahawk Land Attack (Non-Nuclear) Operational Concept

- Launch platform dependent
- Ground launched
- Ship launched
- Submarine launched
- Aircraft launched
- Elements common to all launches
- Suppressed infrared, visual and radar cross section signatures
- TERCOM update points/map grids
- Defense avoidance (to avoid SAM site)
- Defense avoidance (to avoid fighter base)
- DSMAC (Digital Scene Matching Area Correlator) scenes
- Terrain following
- Very low altitude
- Terrain masking
- Terminal guidance phase, using optical sensor
- Target

Source: Joint Cruise Missiles Project Office.
Accuracy of Cruise Missiles
The US developed and deployed CMs without coherent plan that considered the offensive, defensive, and long-range impact of their deployment.

Military history —

• Cruise missiles were the US countermeasure to the heavy Soviet investment in air defenses
• They capitalized on the temporary US lead in this technology
• However, the US is more vulnerable to CMs than Russia due to the proximity of potential targets to the sea shores.
Implications of Cruise Missiles – 2

Implications for U.S. security—

• Very small (hard to find with National Technical Means)
• Can be based almost anywhere (hard to count)
• Dual capable (almost impossible to distinguish nuclear from high-explosive warhead)
• Cheap (can be produced in large numbers)

Several countries could develop a mechanism to launch SRBMs, MRBMs, or land-attack cruise missiles from forward-based ships or other platforms
Part 4: Ballistic Missiles
Air Breathing Delivery Systems (Bombers & Cruise Missiles) vs Ballistic Missiles

Air breathing systems:
- carry the fuel on board but take the oxidizer from the atmospheres \(\Rightarrow\) operate endo-atmospheric

Ballistic missiles:
- carry fuel and oxidizer \(\Rightarrow\) can operate exo-atmospheric
Attributes of Ballistic Missiles

Basing modes —
• Fixed (e.g., blast-hardened silos in the ground)
• Mobile (e.g., on railroad cars)

Propellants —
• Liquid (fuel and oxidizer are separate)
• Solid (fuel and oxidizer are mixed)

Payloads —
• Single warhead + penetration aids (“penaids”)
• Multiple warheads + penetration aids
Physics 280: Session 15

Plan for This Session

News

Module 5: Nuclear Weapon Delivery Systems
Russia warns North Korea over threats of nuclear strike

One of Pyongyang’s few remaining allies says country is in danger of creating legal grounds for international military intervention.

Chad O’Carroll for NK News, part of the North Korea network
Tuesday 8 March 2016 09.34 EST

Russia has warned North Korea that threats to deliver “preventive nuclear strikes” could create a legal basis for the use of military force against the country, suggesting that even Pyongyang’s few remaining friends are growing concerned about its increasingly confrontational stance.

The Russian foreign ministry statement, which follows a North Korean threat to “annihilate” the US and South Korea, also criticises Washington and Seoul for launching the largest joint military drills yet to be held on the peninsula.

“Pyongyang should be aware of the fact that in this way the DPRK will become fully opposed to the international community and will create international legal grounds for using military force against itself in accordance with the right of a state to self-defense enshrined in the United Nations Charter,” continued the statement, translated by Itar Tass news agency.

Washington and Seoul launched their annual joint military exercises on the peninsula on Monday, stepping up the manoeuvres in response to North Korea’s fourth nuclear test in January and rocket launch in February.
News: UK Increases Funds for Trident Upgrade

Trident replacement programme to get £640m additional funding

By Karthick Arvinth
March 3, 2016 06:51 GMT

The controversial Trident nuclear deterrent programme is to receive an additional investment of £640m ($900m), reports say, despite a Commons vote on the issue not expected until later this year. Defence Secretary Michael Fallon is expected to announce the move at a Scottish Conservative Party conference in Edinburgh on 4 March.

It will bring the total amount already spent on the Trident replacement programme to nearly £4bn. The decision is likely to trigger anger from the SNP, who oppose the presence of nuclear weapons in Scottish waters.

Investment sofar: £4 Billion
Total expected cost: £31 Billion

Opposition from Labor, SNP, awaits vote.

The total cost of the Trident replacement programme, which is scheduled to be completed in the early 2030s, is estimated at £31bn.

"Claims that our deterrent is not needed, is easily detected, provocative or too expensive are bunk," Fallon will say. "All of these arguments have one thing in common. They are a desperate attempt to find a fig leaf to cover up [Labour’s] opposition to our nuclear deterrent.

"The simple truth is that Labour is ideologically committed to scrapping the deterrent. They need to be honest about the consequences. They would make the world more dangerous, not safer."

Labour leader Jeremy Corbyn proposed a compromise on the Trident programme earlier this year, in which the four Trident-missile carrying submarines remain part of Britain’s underwater fleet but go to sea without nuclear warheads on board. Fallon rejected the proposal in January and likened it to going to a fight with imitation weapons.
Trident base workers exposed to radiation

Safety breach at Faslane in 2012 led to workers receiving low dose of radiation while repairing nuclear submarine

Press Association
Sunday 6 March 2016 08,59 EST

Twenty workers were exposed to radiation at the Faslane nuclear base in Scotland as a result of a safety breach, according to newly released documents.

The workers were inadvertently exposed to a low dose of ionising radiation as they were repairing a leaking tank on a Trident nuclear submarine at the same time as a nearby reactor was undergoing trials.

The Ministry of Defence said no one was harmed in the incident, which took place in August 2012.
News: Trident Release of Low Level Radiation in Accident

“There was a prolonged and repeated failure of the ship’s staff to understand and control the radiological hazard that they were creating,” it said.

Other documents obtained by the group reveal that in April 2012 a training team was allowed to visit a submarine and enter a radiation exclusion zone without being issued with dosimeters, which measure exposure to ionising radiation.

In February 2013, a sailor working on a submarine at the base left it with a sponge bung without having it checked for contamination.

A fourth incident in December 2013 involved an employee of Babcock, which manages the Faslane site, who removed some grills from an external tank and put his head inside, exposing himself to a small dose of radiation.

The SNP defence spokesman, Brendan O’Hara, said: “The MoD – once again – stands accused of a very poor approach to radiation safety at the Faslane base. When it comes to protecting our armed forces personnel, the contractors working at the base, as well as the wider community, nuclear safety must be paramount.
Categories of Ballistic Missiles Based on Their Ranges (Important)

Short-range ballistic missiles (SRBMs) —
  • Ranges under 1,000 km

Medium-range ballistic missiles (MRBMs) —
  • Ranges between 1,000 km and 3,000 km

Intermediate-range ballistic missiles (IRBMs) —
  • Ranges between 3,000 km and 5,500 km

Intercontinental-range ballistic missiles (ICBMs, SLBMs) —
  • Limited-range ICBMs (LRICBMs): 5,500 to 8,000 km
  • Full-range ICBMs (FRICBMs): > 8,000 km
  • Ranges of US and Russian ICBMs are ~ 12,000 km

These categories are not fluid, because they are based on the performance characteristics of the missile.
Categories of Ballistic Missiles Based on Their Ranges (Important)

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Source: national air and space intelligence center
“Ballistic and Cruise Missile Threat”, 2009
Phases of Flight of Intercontinental-Range Ballistic Missiles (Important)

Basic phases of flight of a (MIRVed) intercontinental ballistic missile (ICBMs and SLBMs) —

- Boost phase: rocket motors burning
- Post-boost phase (release of payload from bus)
- Midcourse phase: ballistic motion in space
- Terminal phase: re-entrance into atmosphere and passage through atmosphere
Phases of Flight of Intercontinental-Range Ballistic Missiles (Important)

- **Boost phase**: rocket motors burning
- **Post-boost phase** (release of payload from bus)
- **Midcourse phase**: ballistic motion in space
- **Terminal phase**: passage through atmosphere

**POST BOOST PHASE**
Categories of Ballistic Missiles Based on Their Purposes

Tactical ballistic missiles (TBMs) —
- For use on the battlefield (e.g., on a particular front)
- Usually have shorter ranges (SRBMs)

Theater ballistic missiles (TBMs) —
- For use in an entire theater of war (e.g., the Middle East)
- Usually have longer ranges than tactical missiles

Strategic ballistic missiles (an example of SNDVs – Strategic Nuclear Weapons Delivery Vehicle) —
- For attacking the homeland of the adversary
- May have longer, possibly intercontinental ranges

These categories are fluid, because they are based on the intent of the user at the time the missile is fired.
Missile Guidance Technologies

Inertial —
  • Uses gyroscopes and accelerometers
  • No contact with outside world

Stellar —
  • Star trackers update inertial guidance system

Satellite —
  • Uses accurate (atomic) clocks on satellites
  • Uses coded radio transmissions
  • Uses sophisticated receivers
  • Can determine both position and velocity very accurately using signals from 3 to 4 satellites
Trajectories and Phases of Flight of Missiles With Various Ranges

Ground range, km

Altitude, km

Boost phase:
- 30-40 s, 10-15 km
- 60-90 s, 40-60 km
- 80-140 s, 100-120 km
- 170-300 s, 180-220 km

Total flight:
- 2 minutes
- 6 minutes
- 13 minutes
- 30 minutes

Apogee:
- ~650 km
- ~1300 km

Endoatmosphere
Exoatmosphere

Target

Boost Phase

Courtesy of D. Moser

Target

Ground range, km

100 200 300 400 500 600

100 200 300 400 500 600 700 800 900 1000 1100 1200 1300

= Boost Phase

16p280 Delivery Systems, p. 55
FKL, Dep. of Physics © 2016
Proliferation of Ballistic Missile Technologies

- USA
  - Taiwan
  - South Korea
  - Argentina
  - Pakistan
  - Bulgaria
  - Vietnam
- South Africa
- UK
- Germany
- Brazil
- Egypt
- Afghanistan
- Israel
- Soviet Union/Russia
- North Korea
- Yemen
- Syria
- Iran
- Libya
- Saudi-Arabia
- France
- India

16p280 Delivery Systems, p. 56
Soviet Scud Missiles and Derivatives - 1

Soviet Scud-B Missile
(based on the German V2)
Range: 300 km

Iraqi Al-Hussein SRBM
Range: 600–650 km
Pakistan’s Ghauri MRBM and transporter (range 1,300 km).
It is almost identical to North Korea’s No Dong MRBM, which is based on Scud technology that North Korea got from Egypt in the 1970s.
Titan Family of Missiles and Launch Vehicles

1959 – 2005 ICMB & civilian uses

103 feet
Titan terror explodes in the Arkansas hills

Shortly after sunset one day last week, a maintenance worker on the third level of a silo housing a 103-ft. Titan II Intercontinental ballistic missile near Damascus, in the Arkansas hills north of Little Rock, dropped the socket of a wrench. The 3-lb. tool plummeted 70 ft. and punctured a fuel tank. As flammable vapors escaped, officials urged the 1,400 people living in a five-mile radius of the silo to flee. The instructions: "Don't take time to close your doors—just get out." And with good reason. At 3:01 a.m., as technicians gave up trying to plug the leak and began climbing from the silo, the mixture of fuel and oxygen exploded. Orange flames and smoke spewed out, lighting up the sky over Damascus. The blast blew off a 750-ton concrete cover. One worker was killed; 21 others were hurt.

Today: LGM-30G Minuteman III ➔ 3 stage solid rocket fuel
Range: 11,000km +
Speed: 24,100 km/h or 6.7km/s (terminal phase)
Which one of the following technologies was not crucial in developing militarily useful cruise missiles?

A. Light carbon fiber materials for the airframes
B. More efficient engines
C. Much smaller and more capable computers
D. GPS and other methods for more accurate guidance
E. “Stealth” technologies to make them harder to detect
iClicker Question
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B. Ship-launched ballistic missiles
C. Land-based intercontinental ballistic missiles
D. Land-based intercontinental bombers
iClicker Question
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iClicker Question

Which one of the following strategic nuclear delivery vehicles can be recalled after launch?

A. Submarine-launched ballistic missiles
B. Land-based intercontinental ballistic missiles
C. Land-based intercontinental bombers
iClicker Question
iClicker Question

Which one of the following strategic nuclear delivery vehicles can be recalled after launch?

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C. Land-based intercontinental bombers
Re-Entry Vehicles (RVs)

Basic types —

• MRV = multiple RV
  — Final stage carries more than 1 RV
  — Final stage has no propulsion
  — RVs are not independently targetable

• MIRV = multiple, independently targetable RV
  — Final stage carries more than 1 RV
  — Final stage has guidance package and propulsion
  — RVs are independently targetable

• MARV = maneuverable RV
  — RV has a guidance package
  — RV maneuvers during the terminal phase, using, e.g., thrusters or aerodynamic forces

MK21 re-entry vehicles on Peacekeeper MIRV bus
MIRV Technology

MX Peacekeeper MIRV

Soviet ICBM MIRV
MX Peacekeeper missile tested at Kwajalein Atoll

Source: www.smdc.army.mil/kwaj/Media/Photo/missions.htm
Minuteman ICBM (Schematic)
Flight of a Minuteman ICBM (Schematic)

- 1st Stage Boost (T = 0 sec.)
- 2nd Stage Ignition (T = 60 sec. typ.)
- 3rd Stage Ignition (T = 120 sec. typ.)
- 3rd Stage Thrust Termination (T = 180 sec. typ.)
- RV Deployment & Backaway
- PBV Burn
- Axial Attitude Control
- RV & Chaff Reentry
- Chaff Deployment
- Shroud Ejection

Target

- Warhead Armed
- Warhead Detonation (Air Burst)
- Warhead Detonation (Ground Burst)
Flight of MIRV’d ICBMs

Four phases of the flight of an intercontinental-range missile armed with MIRVs (Multiple Independently Targetable Reentry Vehicles)—

- **Boost phase** (lasts about 1–5 min)
  - Rocket motors are burning
  - Missile rises through the atmosphere and enters near-Earth space
  - Stages drop away as they burn out

- **Post-boost phase** (lasts 5–10 min)
  - Bus separates from the final stage
  - Bus maneuvers and releases RVs

- **Midcourse phase** (lasts about 20 min)
  - RVs fall ballistically around the Earth, in space

- **Terminal phase** (lasts about 20–60 sec)
  - RVs re-enter the Earth’s atmosphere and encounter aerodynamic forces
  - RVs fall toward targets, until detonation or impact
Examples of US and Russian ICBMs

Recent US ICBMs —

• MX  Solid-propellant, range ~ 12,000 km, 10 warheads  (Peacekeeper, retired 2005)
• MMIII Solid-propellant, range ~ 12,000 km, 3 warheads (Minuteman)

Recent Russian ICBMs —

• SS-24 Solid-propellant, range > 9,000 km
• SS-25 Solid-propellant, range > 9,000 km
• SS-27 Solid-propellant, range > 9,000 km
current land based US ICBMBs

TITAN II

MINUTEMAN II

MINUTEMAN III

PEACEKEEPER

METERS
30
20
10
0

NUMBER DEPLOYED WARHEADS
1
4

MAX RANGE (KM)
12,000
12,500

LAUNCH MODE
Hot
Hot

US ICBMs

* As of early 1987

450
540
10

1
3
Up to 10

Hot
Hot
Cold
US ICBMs – 2

Launch of a Minuteman ➔ video!

Launch of an MX
Russian, Chinese (and North Korean) ICBMs – 1

Source: national air and space intelligence center
“Ballistic and Cruise Missile Threat”, 2009
<table>
<thead>
<tr>
<th>Missile</th>
<th>Number of Stages</th>
<th>Warheads per Missile</th>
<th>Propellant</th>
<th>Deployment Mode</th>
<th>Maximum Range* (miles)</th>
<th>Number of Launchers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Russia</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS-18 Mod 4</td>
<td>2 + PBV</td>
<td>10</td>
<td>Liquid</td>
<td>Silo</td>
<td>5,500+</td>
<td>104</td>
</tr>
<tr>
<td>SS-18 Mod 5</td>
<td>2 + PBV</td>
<td>10</td>
<td>Liquid</td>
<td>Silo</td>
<td>6,000+</td>
<td>(total for Mods 4 &amp; 5)</td>
</tr>
<tr>
<td>SS-19 Mod 3</td>
<td>2 + PBV</td>
<td>6</td>
<td>Liquid</td>
<td>Silo</td>
<td>5,500+</td>
<td>122</td>
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<tr>
<td>SS-25</td>
<td>3 + PBV</td>
<td>1</td>
<td>Solid</td>
<td>Road-mobile</td>
<td>7,000</td>
<td>201</td>
</tr>
<tr>
<td>SS-27 Mod 1</td>
<td>3 + PBV</td>
<td>1</td>
<td>Solid</td>
<td>Silo &amp; road-mobile</td>
<td>7,000</td>
<td>54</td>
</tr>
<tr>
<td>SS-27 Mod-X-2</td>
<td>3 + PBV</td>
<td>Multiple</td>
<td>Solid</td>
<td>Silo &amp; road-mobile</td>
<td>7,000</td>
<td>Not yet deployed</td>
</tr>
<tr>
<td><strong>China</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSS-3</td>
<td>2</td>
<td>1</td>
<td>Liquid</td>
<td>Silo &amp; transportable</td>
<td>3,400+</td>
<td>10 to 15</td>
</tr>
<tr>
<td>CSS-4 Mod 2</td>
<td>2</td>
<td>1</td>
<td>Liquid</td>
<td>Silo</td>
<td>8,000+</td>
<td>About 20</td>
</tr>
<tr>
<td>CSS-10 Mod 1</td>
<td>3</td>
<td>1</td>
<td>Solid</td>
<td>Road-mobile</td>
<td>4,500+</td>
<td>Fewer than 15</td>
</tr>
<tr>
<td>CSS-10 Mod 2</td>
<td>3</td>
<td>1</td>
<td>Solid</td>
<td>Road-mobile</td>
<td>7,000+</td>
<td>Fewer than 15</td>
</tr>
<tr>
<td><strong>North Korea</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taepo Dong 2</td>
<td>2</td>
<td>1</td>
<td>Liquid</td>
<td>Undetermined</td>
<td>3,400+</td>
<td>Not yet deployed</td>
</tr>
</tbody>
</table>

Source: national air and space intelligence center
“Ballistic and Cruise Missile Threat”, 2009
Russian, Chinese (and North Korean) ICBMs – 3
US and Russian SSBNs

US

POSEIDON SSBN

POSEIDON 129.5m 16 Tubes

TRIDENT (OHIO-Class) SSBN

TRIDENT 170.7m 24 Tubes

USSR

YANKEE-Class

YANKEE I 130m 16 Tubes SS-N-6
YANKEE II 130m 12 Tubes SS-N-17

DELTA-Class

DELTA I 140m 12 Tubes SS-N-8
DELTA II 155m 16 Tubes SS-N-8
DELTA III 155m 16 Tubes SS-N-18
DELTA IV 160m 16 Tubes SS-N-23

TYPHOON-Class

TYPHOON 170m 20 Tubes SS-N-20

Borei-Class

170 m, 20 Tubes

retired 1991

phased out 2012

retired 1992
Physics 280: Session 16

Plan for This Session

Questions

Midterm Review, Sunday, March 13th, Loomis 136, 3-5pm
Office Hours, Wednesday, March 16th, 404 Grainger, 12-6pm
Midterm Exam, Thursday March 17th, 1000 Lincoln Hall, 2-3.20pm

Module 5: Nuclear Weapon Delivery Systems
North Korea's Kim says country has miniaturized nuclear warheads

SEUL | BY JACK KIM

North Korean leader Kim Jong Un said the country has miniaturized nuclear warheads to mount on ballistic missiles and ordered improvements in the power and precision of its arsenal, state media reported on Wednesday.

Kim has called for his military to be prepared to mount pre-emptive attacks against the United States and South Korea and stand ready to use nuclear weapons, stepping up belligerent rhetoric after coming under new U.N. and bilateral sanctions for its nuclear and rocket tests.
US Trident SSBN (14 SSBNs, 4 SSGNs)

Trident Missile Tubes With Covers Open

24 Trident C4 SLBMs
8 MIRVs with 100kt W76 ➔ up to 192 targets
SLBM range 7400 km

Trident Submarine Underway

speed : 20 knots
SSBN range : unlimited
deployment : 70-90 days, two rotating crews
Displacement : 16500 tons
Length : 170 m
width : 13 m
Cold Launch Mode

Missile is ejected with high pressure steam before rocket engines are started: “Cold Launch”
US Trident SSBN

Launch video
Submarine-Based Missiles

US SLBMs —

- Trident C4 missiles carried 8 MIRVs each (solid propellant, range 7400 km)
- Trident D5 missiles carry 8 MIRVs each (solid propellant, range 7400 km)

Russian SLBMs —

- SS-N-8 missiles carried 1 warhead each (range 9100 km)
- SS-N-18 missiles carried 3 warheads each (liquid propellant, range 6500 km)
- SS-N-20 missiles carried 10 warheads each (solid propellant, range 8300 km)
- SS-N-23 missiles carried 4 warheads each (liquid propellant, range 8300 km)
US and Russian SLBMs

Nuclear Submarine-Launched Ballistic Missiles

USSR

SS-N-6
SS-N-8
SS-N-17
SS-N-18
SS-N-20
SS-N-23

US

POSEIDON SLBM C-3
TRIDENT SLBM C-4

METERS
15
10
5
0

SS-N-5s not shown

RVs
1
2
3
MOD
MOD
MOD

RANGE (KM)
2,400
3,000
3,000
1,780
9,100
3,900
1,360
6,500
1,800
6,500
1,800
6,300
1,800
8,300
1,800
10 MIRVs
4,000
10 MIRVs
7,400

10 MIRVs
8,300
8 MIRVs
7,400
Part 5: Technical and Operational Aspects
MTCR: Range-Payload Limits

MTCR is the 1987 Missile Technology Control Regime to restrain missile exports

A. Karp, Ballistic Missile Proliferation, sipri, 1996, p. 157
34 member countries (the leading missile producing countries have agreed to restrict missile exports). China and Israel are not members but have agreed unilaterally to adhere to the provisions of the agreement.
The Performance Required for Missile Warheads Increases Greatly with Increasing Missile Range

- Flight altitude (km)
- Reentry velocity (km/s)
- Max. deceleration (m/s²)
- Heat absorption (MJ)

Range (km)
How Does this Translate into Challenges During Re-Entry into the Atmosphere?

Large frictional forces on re-entry lead to

- deceleration up to $500 \text{ m/s}^2 = 51 \text{ g}$
  ~ car with 70mph into concrete wall
  g-forces can be lethal if $> 25 \text{ g}$

- 200 MJ of energy is enough to heat
  2 W76 warheads to the melting temperature
  of iron ~ 1540°C!
Missile Range–Accuracy Tradeoff

CEP: circular error probable (random error)
50% of missiles land within CEP from target
93% within 2 x CEP from target

A. Karp, Ballistic Missile Proliferation, sipri, 1996, p. 112
Ballistic Missile Accuracy

Distribution of RV impact points —

CEP: circular error probable (random error)
50% of missiles land within CEP, 93% within 2 x CEP from target
Ballistic Missile Accuracy

The accuracy of a ballistic missile—like the value of any physical quantity—can only be specified \textit{statistically}.

Important concepts:

- $D =$ total miss distance
- $\text{CEP} =$ “circular error probable” (random error)
- $B =$ Bias (systematic error)

Relation —

$$D = (B^2 + \text{CEP}^2)^{1/2}$$

$\text{CEP}$ is \textit{not} a measure of the miss distance. The miss distance is \textit{at least as large} as the CEP, but can be \textit{much larger} if there is significant bias.
## Ballistic Missile Accuracy

<table>
<thead>
<tr>
<th>Missile</th>
<th>CEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>US MMIII</td>
<td>220 m</td>
</tr>
<tr>
<td>Trident II</td>
<td>100 m</td>
</tr>
<tr>
<td>Russia SS-18</td>
<td>450 m</td>
</tr>
<tr>
<td>Russia SS-27</td>
<td>350 m</td>
</tr>
<tr>
<td>Russia SS-27 Sickle B</td>
<td>200 m</td>
</tr>
</tbody>
</table>
ICBM Accuracy & Vulnerability

Missile accuracy steadily improved during the Cold War as the result of technological innovation.

As ICBMs become more accurate, they become more vulnerable to attack by the adversary, increasing crisis instability.

Each ICBM and each SLBM was armed with more and more warheads during the Cold War.

As each missile was armed with more warheads, it became a greater threat to the nuclear forces of the adversary and a more attractive target for a pre-emptive or first strike, increasing crisis instability.
Silo-Based Missiles

Vulnerable to attack

- Silo locations are known very accurately
- MIRVed missiles make it possible to launch several warheads against an array of silos

Effect of silo hardness

- Hardening is expensive
- US assumes its silos can withstand 2,000 psi (5 psi will completely destroy a brick house)
- US assumes Russian silos can withstand 5,000 psi (example of ‘worst-case’ analysis)
- To destroy a silo this hard, a 300 kt warhead would have to land within 100 m
Silo-Based Missiles

Effect of missile accuracy

- Theoretically, missile survival is very sensitive to the miss distance $D$ of incoming warheads

- An example, assume
  - 1,000 Minuteman silos are hardened to 2,000 psi
  - Two 1.5 MT warheads are targeted to explode at ground level on each silo

- Computations predict
  - If $D = 300$ ft, then 20 missiles survive (60 if 5,000 psi)
  - If $D = 500$ ft, then 200 missiles survive (600 if 5,000 psi)
Sources of Systematic Error

- Gravitational field variations
- Atmospheric drag variations
Gravitational Field Variations

Some possible causes —

• Bumps on the Earth (mountains)
• Mass concentrations (masscons)
• Gravitational pull of the Moon
  (Motion of the Moon changes $g$ by 3 ppm. An error in $g$ of 3 ppm introduces a bias of 300 ft.)

The Earth’s gravitational field is carefully measured over US and R (E-W) test ranges —

• US: Vandenberg to Kwajalein
• R: Plesetsk to Kamchatka and Tyuratam to Pacific

But wartime trajectories would be N-S over pole.
Atmospheric Drag Variations

Some possible sources —

- Jet streams
- Pressure fronts
- Surface winds
  (30 mph surface wind introduces a bias of 300 ft.)

Density of the atmosphere —

- Is a factor of 2 greater in the day than at night
- Varies significantly with the season
- Is affected by warm and cold fronts

Data from military weather satellites and from models of weather over SU targets were reportedly used to update US warheads twice per day
Uncertainties on Silo-Based Missiles

Fundamental uncertainties

- Missile accuracy
- Warhead yield
- Silo hardness

Operational uncertainties

- System reliability
- Wind and weather
- Effects of other warheads (fratricide)
- Extent of ‘collateral damage’
  (‘digging out’ missiles creates enormous fallout)
Probability of destroying (“killing”) a missile silo:

• A 10-fold increase of warhead yield $Y$ increases the kill factor $K$ by about a factor of 5.

• A 10-fold decrease in the warhead miss distance $D$ increases the kill factor $K$ by 100.

• For a kill factor of 20, a 10-fold increase in the silo hardness from 300 psi to 3000 psi reduces the probability of silo destruction from about 85% to about 35%.
Counterforce Capabilities

U.S. ICBMs: \( K = 107,000 \)

U.S. Trident II D5: \( K = 475,000 \)

Russia ICBMs: \( K = 131,000 \)

Russia SLBMs: \( K = 9,500 \)
Submarine-Based Missiles

Operational considerations

• Vulnerability depends on size of operational areas, ASW threat, counter-ASW capability

• Ability to survive

• US SSBNs are quieter than Russian SSBNs (but Russia is improving rapidly)

• US leads in anti-submarine warfare (ASW) capability and access to high seas

• Fraction of forces on-station (duration of patrols, time required for repairs)

• System reliability

• Effectiveness of command and control
Submarine-Based Missiles

Effective number of warheads (example) before New START

- **United States**
  
  \[
  \begin{align*}
  2688 & \quad [\text{SLBM warheads}] \\
  \times 0.75 & \quad [\text{fraction typically on-station}] \\
  \times 0.90 & \quad [\text{estimated reliability}] \\
  = 1,814 & \quad [\text{effective number of warheads}]
  \end{align*}
  \]

- **Russia**
  
  \[
  \begin{align*}
  2384 & \quad [\text{SLBM warheads}] \\
  \times 0.25 & \quad [\text{fraction typically on-station}] \\
  \times 0.70 & \quad [\text{estimated reliability}] \\
  = 447 & \quad [\text{effective number of warheads}]
  \end{align*}
  \]

These examples show that many factors *other than just the number of warheads* are important in comparing the effectiveness of nuclear forces.
Module 5: Nuclear Delivery Systems

Part 5: Nuclear Command and Control
C3I: Command, Control, Communication, Intelligence

Specific goals—

• Provide strategic and tactical warning
• Provide damage assessments
• Execute war orders from National Command Authority before, during, and after initial attack
• Evaluate effectiveness of retaliation
• Monitor development of hostilities, provide command and control for days, weeks, months
Some important aspects and implications —

- Organizational structure of command and control
- Available strategic communications, command, control and intelligence (C3I) assets
- Vulnerability of strategic C3I assets to attack

Alert levels — (Defensive Readiness Condition)

**DEFCON 5** Normal peacetime readiness
**DEFCON 4** Normal, increased intelligence and strengthened security measures
**DEFCON 3** Increase in force readiness above normal readiness intelligence and strengthened security measures
**DEFCON 2** Further Increase in force readiness
**DEFCON 1** Maximum force readiness.
Satellite systems

- Early warning
- Reconnaissance
- Electronic signals
- Weather
- Communication
- Navigation
Response Times for Attack or Breakout

- Risk of accidental nuclear war
- Automatic launch
  - Launch on warning
  - Launch under attack
  - Launch after attack
  - De-alerting
  - Arms control
  - Disarmament

Time for decision-making:
- seconds
- minutes
- hours
- days
- weeks
- months
- years
The Threat of Accidental Nuclear War – 20 Dangerous Incidents

1) November 5, 1956: Suez Crisis Coincidence

2) November 24, 1961: BMEWS Communication Failure


4) August-October, 1962: U2 Flights into Soviet Airspace

5) October 24, 1962: Cuban Missile Crisis: A Soviet Satellite Explodes

6) October 25, 1962: Cuban Missile Crisis: Intruder in Duluth

7) October 26, 1962: Cuban Missile Crisis: ICBM Test Launch

8) October 26, 1962: Cuban Missile Crisis: Unannounced Titan Missile Launch

9) October 26, 1962: Cuban Missile Crisis: Malstrom Air Force Base

10) October, 1962: Cuban Missile Crisis: NATO Readiness

Source: www.nuclearfiles.org/kinuclearweapons/anwindex.html
The Threat of Accidental Nuclear War
20 Dangerous Incidents

11) October, 1962- Cuban Missile Crisis: British Alerts
12) October 28, 1962- Cuban Missile Crisis: Moorestown False Alarm
13) October 28, 1962- Cuban Missile Crisis: False Warning Due to Satellite
14) November 2, 1962: The Penkovsky False Warning
15) November, 1965: Power Failure and Faulty Bomb Alarms
16) January 21, 1968: B-52 Crash near Thule
17) October 24-25, 1973: False Alarm During Middle East Crisis
18) November 9, 1979: Computer Exercise Tape
19) June, 1980: Faulty Computer Chip
20) September, 1983: Russian False Alarm
21) November, 1983 Able Archer
21) January, 1995: Russian False Alarm (Norwegian research missile)

Source: www.nuclearfiles.org/kinuclearweapons/anwindex.html
On January 25, 1995, the Russian early warning radar's detection of an unexpected missile launch near Spitzbergen. The estimated flight time to Moscow was 5 minutes. The Russian President, the Defense Minister and the Chief of Staff were informed. The early warning and the control and command center switched to combat mode. Within 5 minutes, the radar's determination that the missile's impact would be outside the Russian borders.

The missile was Norwegian, and was launched for scientific measurements. On January 16, Norway had notified 35 countries including Russia that the launch was planned. Information had apparently reached the Russian Defense Ministry, but failed to reach the on-duty personnel of the early warning system.
Possible Risk Reduction Measures

• Put ballistic missiles on low-level alert
• Reduce number of warheads on missiles
• Remove warheads to storage
• Disable missiles by having safety switches pinned open and immobilized
• Allow inspections and cooperative verification

End of Module 5
Flight of a MIRV’d ICBM (Schematic)
Flight of a MIRV’d ICBM (Schematic)

1. The missile launches out of its silo by firing its 1st stage boost motor (A).
2. About 60 seconds after launch, the 1st stage drops off and the 2nd stage motor (B) ignites. The missile shroud is ejected.
3. About 120 seconds after launch, the 3rd stage motor (C) ignites and separates from the 2nd stage.
4. About 180 seconds after launch, 3rd stage thrust terminates and the Post-Boost Vehicle (D) separates from the rocket.
5. The Post-Boost Vehicle maneuvers itself and prepares for re-entry vehicle (RV) deployment.
6. The RVs, as well as decoys and chaff, are deployed during backaway.
7. The RVs and chaff re-enter the atmosphere at high speeds and are armed in flight.
8. The nuclear warheads detonate, either as air bursts or ground bursts.